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Justification of Lever Arrangement Parameters for Friction-Type Traction Gear

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Abstract

The paper reviews the current state and application potential of the friction-type traction gear as applied for rail-guided vehicles used in mining operations. It presents a design concept of a friction-type traction gear with a lever arrangement. A kinematic diagram of the lever arrangement is provided. Optimal geometry of the key elements of the lever arrangement is defined. The analytical model of the power load on the levers is developed. A correlation between the geometry of the key lever arrangement elements and the reduction rates was established with account for operating conditions of the traction vehicle. Design recommendations for friction-type traction gear are given based on the analysis of the obtained results.

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Keywords: mining operations; rail-guided vehicles; traction gear; lever arrangement; reduction rate

1. Introduction

Rail-guided vehicles are widely used both in underground and surface mining [1, 2]. Depending of the specific tasks, these vehicles can use monorail or double-rail tracks on surface or telpher lines. However, their application is limited due to various mining factors including the route terrain profile, tramming angles, rail surface soiling and icing of various types, etc. [3].

In Former USSR, all issues concerned with operation of rail-guided vehicles at mining operations were tackled by a number of research organizations including the Skochinsky Institute of Mining, VNII Giprougol, Giprouglegormash, Makeevka Research Institute for Mining Safety, Leningrad Mining Institute, Moscow Mining

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Institute, etc. Their research proved that a promising engineering solution to the investigated problems is designing of special-purpose rail-guided vehicles using the friction-type or gear-tooth systems. A key challenge in creation of traction gears is to correlate their design parameters with the operation environment.

Ferrit s.r.o. (Czech Republic), Becker Mining Systems and SMT Scharf Gruppe (Germany) are currently among the international leaders in manufacturing of the friction-type and gear-tooth traction vehicles. In the friction-type traction vehicles designed by these companies, the pressing force of the traction wheels is created by a hydraulic system. Despite a positive service experience of these traction vehicles, their practical application can be limited by a rather bulky hydraulic power packs and supply line.

2. Identification of Research Objectives

An alternative design is represented with friction-type traction vehicles, where the pressing force of the traction wheels against the rail is created with a system of levels and is automatically adjusted by resistance of the transported load. This traction gear was developed by V.S. Bersenev, Professor of the Leningrad Mining Institute [4]. The research team he headed created friction-type traction vehicles that were successfully used in mining of solid minerals, e.g. for transportation of marble block at Koelginskiy Quarry.

Figure 1 shows one of such systems that was used for materials handling in steeply inclined railroad intervals at mining operations. Smooth-faced traction vehicles which are part of the traction vehicle's lever arrangement1, interact with the traction rail 6, which is located in-between the two supporting rails 5. Torque is delivered to the traction vehicles from the asynchronous motor 4 through a worm reduction gearbox 3 mounted on the vehicle's frame 2.

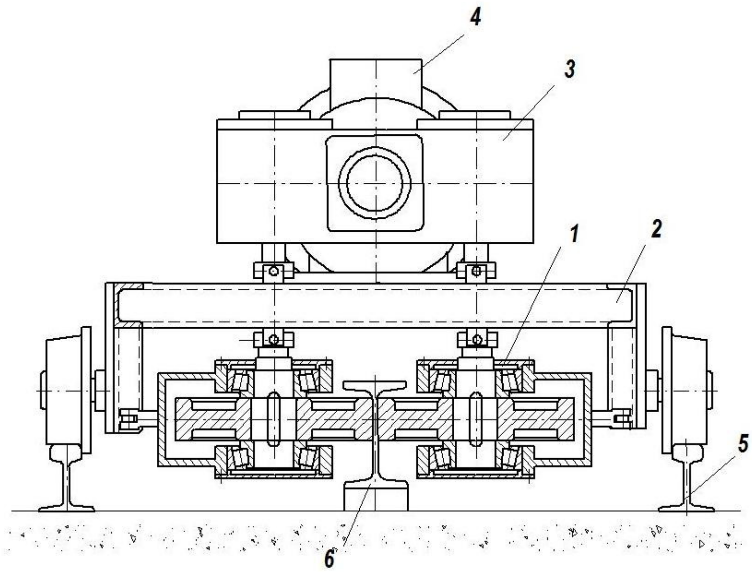

Fig. 1. Traction gear design: 1 – traction vehicle lever arrangement, 2 – traction vehicle frame, 3 – gear assembly, 4 – propulsion motor, 5 – supporting rails, 6 – traction rail

A research team at the Mining University are currently designing friction-type traction gears adjusted for up-to-date requirements towards rail-guided vehicles that operate in complex mining and geological settings. A primary research objective is to enhance structural schemes of the traction vehicle's lever arrangement and to establish a clear correlation between their kinematic parameters and operating conditions of the tracked vehicle.

3. Research Problem Solution

A structural diagram of the traction vehicle's lever arrangement is given in Fig. 2. The traction gear includes traction wheels 1 that close on the traction rail 9. These wheels are mounted on levers 3 using bearings 2; while the levers are attached to the short hauls of the crank levers 7 using hinge joints 5. When the motion is initiated, the initial adhesion of the wheels 1 to the traction rail 9 is secured by the preliminary adhesion assemblies 4. Ends of each pair of crank levers 7 are connected with hinge joints 6 to clamps 8 that envelope the rail. Ends of the short hauls of crank levers 7 are attached to the vehicle's frame 11 using articulated rods 10. Depending on the operating conditions, this traction gear automatically adjust the pressure of the traction wheels 1 against the traction rail 9 through the lever arrangement. Vehicle's traction resistance is used as the input signal to control the pressure of the traction wheels against the rail.

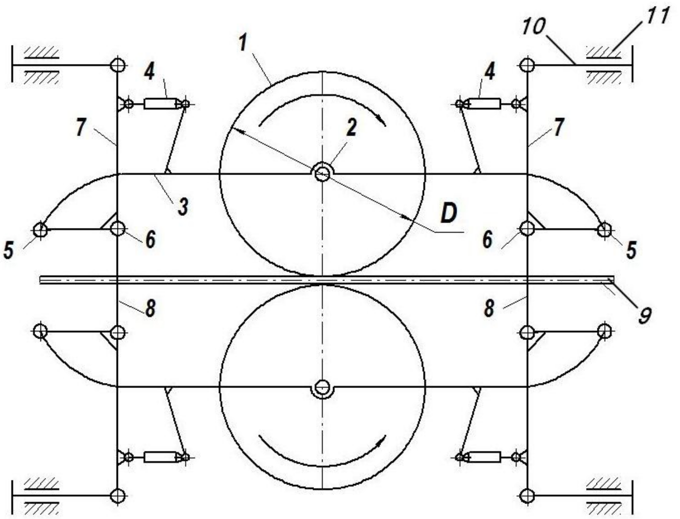

Fig. 2 Kinematic diagram of traction vehicle's lever arrangement: 1 – traction wheel, 2 – bearing, 3 – traction wheel lever, 4 – preliminary adhesion assembly, 5, 6 – hinge joints, 7 – crank lever, 8 – clamp, 9 – traction rail, 10 – articulated rod, 11 – traction vehicle frame

The key characteristic of the traction vehicle's lever arrangement is its reduction rate, which affects pressure of the traction wheels against the traction rail.

The following condition shall be met in order to secure reliable adhesion of the wheel and rail system [5]:

$$u = \frac{1}{\psi_0} \ , \tag{1}$$

where ψ_0 is the adhesive coefficient for a given operation conditions (various types of rail soiling, freezing, etc.).

The calculated reduction rate for the kinematic diagram of the traction vehicle's lever arrangement shown in Fig. 3 equals

$$u = u_7 \cdot u_3 \ , \tag{2}$$

where u_7 is the crank lever reduction rate, and u_3 is the traction wheel lever reduction rate.

Reduction rates u_3 and u_7 are calculated based on the geometry of individual traction gear items for which the following design limitation are introduced.

For design considerations, the length of the traction wheel lever L (Fig. 3) is selected from the following range

$$L = 2D \div 4D \ , \tag{3}$$

where D is the traction wheel diameter.

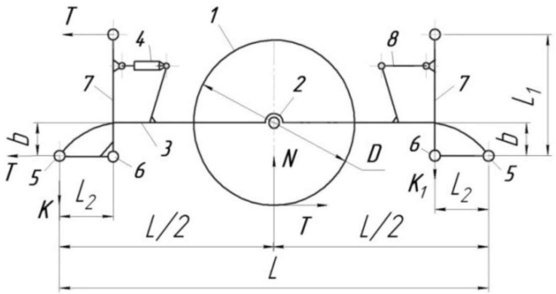

Fig. 3. Analytic power load model of traction wheel lever: 1 – traction wheel; 2 – bearing; 3 – traction wheel lever; 4 – preliminary adhesion assembly; 5,6 – hinge joints; 7 – crank lever; 8 – tight coupling; L – length of traction wheel lever; L_1– long haul of crank lever 7; L_2 – short haul of crank lever 7; b – distance from traction wheel center to center of hinge joint 5

The minimum value of $L = 2D$ secures the required clearances between the moving parts of the lever arrangement, while the maximum of $L = 4D$ prevents clamps 8 of the tracked vehicles from impeding its movement when passing curved sections of the rail track. The traction wheel diameter is determined with due account for back-to-back endurance conditions and is controlled by normal pressure N [6]

$$D \geq \frac{\xi \cdot N}{B \cdot [q]} \ , \tag{4}$$

where ξ is the dynamic factor; B is the width of smooth-faced traction wheels; $[q]$ is traction wheel pressure per unit of the traction rail area.

Apart from the back-to-back endurance conditions, the traction wheel diameter D is also limited by the conventional railroad gage.

The following range of traction wheel diameters was considered: D = 200 mm; 300 mm and 400 mm.

With account for formula (3), the traction wheel lever length L will vary within the range shown in Table 1.

Table 1. Length of traction wheel levers.

Traction wheel diameter D (mm)	Traction wheel lever length L (mm)
200	400÷800
300	600÷1200
400	800÷1600

The other geometrical dimensions of the lever assembly are set to secure the minimum required clearances between the lever hinge joints and the traction gear elements.

Long haul of the crank lever:

$$0{,}375D \leq L_1 \leq 0{,}75D \ . \tag{5}$$

Short haul of the crank lever:

$$0,125D \le L_2 \le 0,25D\,. \tag{6}$$

Distance from the traction wheel center to the center of hinge joint 5:

$$0,125D \le b \le 0,25D\;. \tag{7}$$

The calculated adhesive coefficient ψ is taken to be equal to 0.1, which corresponds to adverse operating conditions of rail-guided vehicles in mining operations (icing, oil spills, etc.).

Reduction rates of the traction vehicle's lever assembly u shown in Table 2 are calculated for the maximum possible values of L_1, L_2, and b.

Table 2. Maximum lever assembly geometry.

D (mm)	$L_{1\max}$ (mm)	$L_{2\max}$ (mm)	$b_{\max}$ (mm)
200	150	50	50
300	225	75	75
400	300	100	100

During operation of the traction vehicle, levers 3 (Fig. 3) do not only exercise the function of structural components bearing the traction wheels, but also act as part of the feedback mechanism that controls the overall reduction rate of the whole assembly. The traction wheels levers are subjected to the following forces: forces K applied to lever 3 by crank lever 7; normal pressure N; tangential reaction T of the rail.

Correlation between forces N and K is the reduction rate of the traction wheels lever, i.e.

$$u_3 = \frac{N}{K}\;. \tag{8}$$

Value u_3 depends on the correlation of the lever dimensions L, L_2, and b.

When force T is transmitted, the right crank lever 7 is lowered to the preliminary adhesion assembly 4 as on an arresting device, thus it is replaced with tight coupling 8.

The equilibrium equation for lever 3 related to the center of the right hinge joint 6 is as follows:

$$\sum M_{(6)} = -K\cdot(L-L_2)+N\cdot(0,5L-L_2)+T\cdot b = 0\,, \tag{9}$$

while $T=\psi\cdot N$, and $u_3 = N/K$, the reduction ratio of the traction wheel lever equals

$$u_3 = \frac{L-L_2}{0,5L-L_2+\psi\cdot b}\;, \tag{10}$$

where ψ is the calculated adhesive coefficient.

The reduction rate of the crank lever is

$$u_7 = \frac{L_1}{L_2}\;. \tag{11}$$

Then, the calculated reduction rate of the traction vehicle's lever arrangement is

$$u = \frac{L_1}{L_2}\cdot\frac{L-L_2}{0,5L-L_2+\psi\cdot b}\;. \tag{12}$$

As it can be seen from formula (12), major impact on the reduction rate of the traction vehicle's lever arrangement is exerted by the reduction rate of the crank lever 7, which maximum values is achieved at $L_1 = 0{,}75D$, $L_2 = 0{,}125D$ and equals $u_7 = 6$. Results of the correlation study between the lever assembly reduction rate u and the length of the traction wheel lever L and the traction wheel diameter D at $u_7 = 6$ are given in Fig. 4.

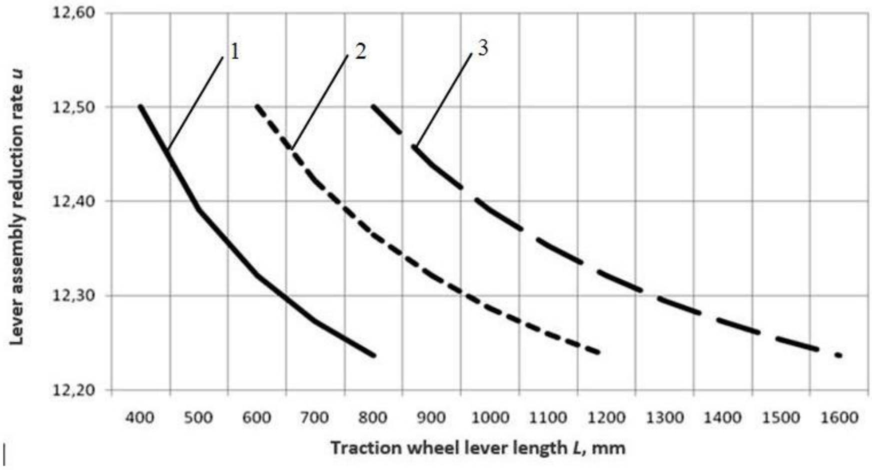

Fig. 4. Dependence of traction vehicle's lever assembly reduction rate u on variations in its main geometric parameters: 1 - D = 200 mm; 2 - D = 300 mm 3 - D = 400 mm

4. Conclusions

Analysis of the obtained dependences (Fig. 4) helped to make the following conclusions:

- Increase in the traction wheel lever length L results in decreasing reduction rate of the traction vehicle's lever assembly u for all the considered traction wheel diameters D.
- Increase in the traction wheel diameter D results in wider range of possible lengths of the traction wheel lever L with unchanged range of reduction rates of the traction vehicle's lever assembly u.
- The range of reduction rates of the traction vehicle's lever assembly u does not depend on the traction wheel diameter D.
- Reduction rates of the traction vehicle's lever assembly $u = 12.24 \div 12.5$ secure reliable adhesion of the smooth-faced traction wheels with the traction rail at the calculated adhesive coefficient $\psi = 0.1$, which corresponds to adverse operating conditions of rail-guided vehicles.

The performed analysis helped to establish that in designing of traction vehicles the traction wheel diameters should be selected within the range of $D = 200 \div 400$ mm with the traction wheel lever length $L = (2{,}0 \div 2{,}5)D$.

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